"On a Self-recovering Coherer and the Study of the Cohering Action of different Metals." By Jagadis Chunder Bose, M.A., D.Sc., Professor of Physical Science, Presidency College, Calcutta. Communicated by Lord Rayleigh, F.R.S. Received March 6,—Read April 27, 1899.

In working with coherers, made of iron or steel, some special difficulties are encountered in the warm and damp climate of Bengal. The surface of the metals soon gets oxidised, and this is attended with variation of sensitiveness of coherer. The sensitiveness, it is true, does not altogether disappear, but it undergoes a considerable diminution. The presence of excessive moisture in the atmosphere introduces another difficulty. Substances to be experimented on become more or less opaque by absorption of water vapour. As fairly dry weather lasts in Bengal only for a few weeks in winter, the difficulties alluded to above are for the greater part of the year serious drawbacks in carrying out delicate experiments. To avoid as far as possible the partial loss of sensibility of the receiver due to oxidation, I tried to use metals less oxidisable than iron for the construction of the coherer. In my earlier experiments I derived considerable advantage by coating the steel spirals with deposits of various metals. Finding that the sensitiveness depends on the coating metal and not on the substratum, I used in my later experiments fine silver threads wound in narrow spirals. They were then coated with cobalt in an electrolytic bath. The coating of cobalt was at first apt to strip off, but with a suitable modification of the electrolyte and a proper adjustment of the current, a deposit was obtained which was very coherent. The contact surface of cobalt was found to be highly sensitive to electric radiation, and the surface is not liable to such chemical changes as are experienced in the case of steel.

I next proceeded to make a systematic study of the action of different metals as regards their cohering properties. In a previous paper* I enumerated the conditions which are favourable for making the coherer sensitive to electric radiation. These are the proper adjustment of the E.M.F. and pressure of contact suitable for each particular receiver. The E.M.F. is adjusted by a potentiometer slide. For very delicate adjustments of pressure I used in some of the following experiments an U-tube filled with mercury, with a plunger in one of the limbs; various substances were adjusted to touch barely the mercury in the other limb. A thin rod, acting as a plunger, was made to dip to a more or less extent in the mercury by a slide arrangement. In this way the mercury displaced was made to make contact with the

* "On Polarisation of Electric Ray," 'Journal of Asiatic Society of Bengal,' May, 1895.

given metal with gradually increasing pressure, this increase of pressure being capable of the finest adjustments. The circuit was completed through the metal and mercury. Sometimes the variation of pressure was produced by a pressure bulb. In the arrangement described above the contact is between different metals and mercury—metals which were even amalgamated by mercury still exhibited sensitiveness to electric radiation when the amalgamation did not proceed too far. In this way I was able to detect the cohering action of many conductors, including carbon. For studying the contact-sensitiveness of similar metals I made an iron float on which was soldered a split-tube in which the given metal could be fixed, a similar piece of metal being adjusted above the float, so that by working the plunger or the pressure bulb the two metals could be brought into contact with graduated pressure. The other arrangements adopted were the contact of spirals compressed by micrometer screw, and filings similarly compressed between two electrodes.

With the arrangement described above the action of radiation on metallic contacts was studied, a brief account of which will be given under their respective groupings. It may here be mentioned that certain metals which do not usually show any contact-sensitiveness can be made to exhibit it by very careful manipulation. The nature of the response of a coherer is to a certain extent modified by its condition and particular adjustment. A coherer freshly made is more difficult to adjust, but at the same time far more sensitive. The action is more easily under control and more consistent after a few days' rest, but the sensitiveness is not so abnormally great. The contacts of bright and clear surfaces are difficult to adjust, but such contacts are more sensitive than those made by tarnished surfaces. Pressure and E.M.F., as previously stated, also modify the reaction. For example, a freshly made and very delicately adjusted coherer subjected to slight pressure and small E.M.F. showed an *increase* of resistance by the action of radiation. The galvanometer spot, after a short interval, resumed its former position, exhibiting a recovery from the effect of radiation. The coherer continued to exhibit this effect for some time, then it relapsed into the more stable condition in which a diminution of resistance is produced by the action of radiation. Another coherer was found apparently irresponsive to radiation, there being the merest throb (sometimes even this was wanting) in the galvanometer spot, when a flash of radiation fell on the receiver. Thinking that this apparent immobility of the galvanometer spot may be due to response, followed by instantaneous recovery, the galvanometer needle being subjected to opposite impulses in rapid succession, I interposed a telephone in the circuit; each time a flash of radiation fell on the receiver the telephone sounded, no tapping being necessary to restore the sensitiveness. The recovery was here automatic and rapid. After twenty

or thirty flashes, however, the receiver lost its power of automatic recovery, and the sensitiveness had then to be restored by tapping. An interesting observation was made to the effect that on the last occasion the receiver responded without previous tapping, a rumbling noise was heard in the telephone which lasted for a short time, evidently due to the re-arrangement of the surface molecules to a more stable condition, after which the power of self-recovery was lost.

The state of sensibility described above is more or less transitory, and is induced, generally speaking, by a somewhat unstable contact and low E.M.F. acting in the circuit. In the majority of metals, the normal tendency is towards a diminution of contact resistance by the action of electric waves. The occasional increase of resistance, in general, disappears when the pressure and E.M.F. are increased. But in the case to be presently described we have an interesting exception, where the normal state of things is just the reverse of what prevails in the majority of metals.

Alkali Metals.

In the following investigations the radiator is a platinum sphere 9·7 mm. in diameter. The coherer was placed at a short distance, so that the intensity of incident radiation was fairly strong.

Potassium.—In working with this metal, the exceptional nature of the reaction became at once evident. The effect of radiation was to produce an *increase* of resistance. The pressure of contact was adjusted till a current flowed through the galvanometer, the galvanometer spot of light being at one end of the scale. On subjecting the receiver to radiation the spot of light was deflected to the opposite end, exhibiting a great increase of resistance. When the pressure and E.M.F. were suitably adjusted a condition was soon attained, when a flash of radiation made the spot of light swing energetically in one direction, indicating an increase of resistance: the receiver, however, recovered instantaneously with the cessation of radiation, and the spot violently swung back to the opposite end, indicating the normal current that flows in the circuit. This condition was found to persist, the receiver uniformly responding with an increase of resistance followed by automatic and instantaneous recovery. To prevent oxidation, the receiver was kept immersed in kerosene. When the receiver was lifted from the protecting bath, it still continued to respond with an increase of resistance, but with a gradual loss of power of automatic recovery. This power was again restored on again immersing the coherer in kerosene. The receiver in vacuo, or under reduced hydrogen pressure, would have been preferred, had the necessary appliances been available.

Sodium.—As we pass from potassium to the neighbouring metals, there is a gradual transition of property as regards the nature of response to electric waves. With sodium the adjustment is a little

more difficult than with potassium, but the response is somewhat similar to that of potassium. Though in general there is an increase of resistance produced by electric radiation, there are occasional exceptions when a diminution of resistance is produced. With some trouble the adjustment could be made so that the recovery is also automatic, but it is not so energetic as in the case of potassium.

Lithium.—Specimens of this metal not being available, I obtained a deposit of it on iron electrodes by electrolysis of the fused chloride. The action produced by electric radiation was sometimes an increase and sometimes a diminution of resistance, the increase of resistance being the more frequent. With some difficulty it was possible to adjust the sensitiveness so that the recovery was automatic, but it was not energetic nor did this power persist for a long time.

Metals of the Alkaline Earth.

Pure metals of this group being not available, I had to rely on the deposit obtained by electrolysis. Chloride of calcium was fused in a crucible, and deposits were produced on iron cathodes, the anode being a carbon rod. The deposit was not very even. One of the iron rods with the deposit was tested by immersion under water, when hydrogen was evolved. I did not succeed in getting deposits of either barium or strontium, the temperature available not being sufficiently high.

On making a coherer with calcium, and keeping it immersed in kerosene, an action similar to that produced by sodium was observed. The tendency of self-recovery was, however, very slight.

Magnesium, Zinc, and Cadmium.

In these metals and in the succeeding groups there is a pronounced tendency towards a diminution of resistance by the action of electric radiation. Magnesium being easily oxidisable, there is a thin coating of oxide on the surface. When this is scraped, the metal makes a very highly sensitive receiver. The adjustment is not difficult, the metal allowing a considerable latitude of pressure and E.M.F. It has already been stated that the metals which are slightly tarnished can be more easily adjusted.

Though there is in this metal a decided tendency towards a reduction of contact resistance, yet it is possible by careful adjustment to obtain an increase of resistance. Indeed it is sometimes possible to so adjust matters that one flash of radiation produces a diminution of resistance, and the very next flash an increase of resistance. Thus a series of flashes may be made to produce alternate throws of the galvanometer needle. The more stable adjustment, however, gives a diminution of resistance, and receivers made with this metal could be made extremely sensitive. The tendency towards recovery is almost wanting.

Zinc.—This metal also exhibits moderate sensitiveness; it, however, requires a more careful adjustment.

Cadmium.—The action of this metal is somewhat similar to that of zinc, but the sensitiveness is very much less.

Bismuth and Antimony.

Both bismuth and antimony make very sensitive receivers. Moderately small E.M.F. with slight pressure is best suited for these metals.

Iron and the Allied Metals.

Iron.—The action of this metal is well known. In one of my experiments I used it in connection with mercury. When the contact is very lightly made, there is a tendency towards an increase of resistance by the action of radiation. But after a time the action became normal, that is to say, there was a diminution of resistance.

Nickel and Cobalt.—These are also very sensitive. The surface being bright, the E.M.F. and pressure are to be adjusted with some care.

Manganese and Chromium.—These were obtained in the form of powder. Their action is similar to the other metals of this group.

Aluminium.—This also makes a sensitive receiver.

Tin, Lead, and Thallium.

It is somewhat difficult to adjust *tin*, but when this is done the metal exhibits fair sensitiveness. *Lead* is also sensitive. The sensitiveness of *thallium* is only moderate.

Molybdenum and Uranium.

The specimen obtained was in the form of powder, and very tarnished in appearance. The sensitiveness exhibited was slight.

Metals of the Platinum Group.

Platinum exhibited a moderate amount of sensitiveness. Spongy platinum also showed the same action. The absorption of hydrogen made the action slightly better, but the improvement was not very marked.

Palladium.—This made a more sensitive coherer than platinum. The adjustment is, however, more troublesome.

Osmium.—The specimen was in the form of powder. It requires a higher E.M.F. to bring it to a sensitive condition. The sensitiveness was moderate.

Rhodium was found to be more sensitive than osmium.

Copper, Gold, and Silver.

Copper required a much smaller E.M.F. The sensitiveness was only moderate.

Gold was more difficult to adjust, but the action is a little stronger.

Silver.—The receiver was extremely unstable. It exhibited sometimes a diminution and at other times an increase of resistance.

It will be seen from the above that all metals exhibit contact sensitiveness to electric radiation, the general tendency being towards a diminution of resistance.

The most interesting and typically exceptional case, however, is the receiver made with potassium, which not only exhibits an increase of resistance by the action of radiation, but also a remarkable power of self-recovery. In the accidental instances of increase of resistance exhibited by other metals, an increase of pressure or E.M.F. generally brought the coherer to the normal condition, which showed a diminution of contact resistance by the action of electric waves. With potassium I gradually increased the pressure till the receiver grew insensitive. All along it indicated an increase of resistance, even when one piece was partially flattened against the other. I increased the E.M.F. many times the normal value; this increase (till the limit of sensitiveness was reached) rather augmented the sensibility and power of automatic recovery. I allowed the receiver a period of rest, the nature of response remaining the same. As far as I have tried, potassium receivers always gave an increase of resistance, a property which seems to be characteristic of this metal, and to a less extent, of the allied metals.

It will thus be seen that the action of potassium receiver is not, strictly speaking, a cohering one. For it is difficult to see how a cohering action and consequent better contact could produce an increase of resistance. It may be thought that the sudden increase of current may, by something like a Trevelyan rocker action, produce an interruption of contact. But such a supposition does not explain the instantaneous action, and the equally instantaneous recovery.

In arranging the metals according to their property of change of contact resistance, I was struck by the similarity of action of electric radiation on potassium in increasing the contact resistance, and the checking action of visible radiation on the spark discharge. In the latter case too potasium is also photo-electrically the most sensitive. But the action is confined to visible radiation, and is most efficient in the ultra-violet region. I was indeed apprehensive that the action on potassium receiver which I observed might be in some way due to the ultra-violet radiation of the oscillatory spark. But this misgiving was put to rest from the consideration that the receiver was placed in a

glass vessel filled with kerosene, through which no ultra-violet light could have been transmitted. To put the matter to final test, I lighted a magnesium wire in close proximity to the receiver without producing any effect. Thick blocks of wood of ebonite and of pitch were interposed without checking the action. I then used polarised electric radiation, and interposed a book analyzer, 6 cm. in thickness; when the analyzer was held parallel, there was a vigorous action, but when it was held in a crossed position all action was stopped. No visible or heat radiation could have been transmitted through such a structure, and there can be no doubt that the action was entirely due to electric radiation.

It would be interesting to investigate whether the observed action of electric radiation on a potassium receiver is in any way analogous to the photo-electric action of visible light. I have commenced an investigation on this subject, the results of which I hope to communicate on another occasion.

BAKERIAN LECTURE.—"The Crystalline Structure of Metals." By J. A. EWING, F.R.S., Professor of Mechanism and Applied Mechanics in the University of Cambridge, and W. ROSENHAIN, 1851 Exhibition Research Scholar, Melbourne University. Delivered May 18, 1899.

(Abstract.)

In a previous communication, read to the Society on March 16, a preliminary account was given of some of the results the authors had arrived at in studying metals by the microscopic methods initiated by Sorby, and pursued by Andrews, Arnold, Behrens, Charpy, Osmond, Roberts-Austen, Stead, and others. The present paper deals with a development and extension of the same work. It relates chiefly, though not exclusively, to the effects of strain, and the relation of plasticity to crystalline structure.

It is well known that the etching of a polished surface of metal reveals, in general, a structure consisting of irregularly shaped grains, with clearly marked boundaries. Each grain is a crystal, the growth of which has been arrested by its meeting with neighbouring grains. This view, as Mr. Stead has pointed out, is strongly supported by the appearance of the etched surface under oblique illumination, when the several grains are seen to reflect light in a way which is consistent only with the idea that on each there is a multitude of facets with a definite orientation, constant over any one grain, but different from grain to grain. The formation of such a structure is well exhibited, on a relatively enormous scale on the inner surface of a cake of solidifying